User Request Evaluation Tool Daily Use Time Shifting Trajectory Prediction Accuracy Degradation Study

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EXECUTIVE SUMMARY

The Traffic Flow Management Branch, ACT-250, at the FAA W. J. Hughes Technical Center (WJHTC) in Atlantic City is tasked to develop scenarios of realistic air traffic for the Accuracy Acceptance Testing of the User Request Evaluation Tool Core Capability Limited Deployment (URET CCLD). The scenarios are required to include a specified quantity of aircraft to aircraft and aircraft to airspace encounters. To induce these encounters using recorded field traffic data, time shifting techniques will be utilized by ACT-250 scenario developers. The overall FAA strategy in the Accuracy Acceptance Testing of URET CCLD also includes a specification refresh using the accuracy measurements of the MITRE developed URET Daily Use (URET DU) system based on the same scenario(s). This strategy mitigates the risk of unfairly testing the URET CCLD system with a set of scenarios with traffic situations more difficult to predict than the field. However, to mitigate that risk further and determine if any risk exists at all, ACT-250 performed a set of experimental runs using the time shifting techniques planned to be used for development of the accuracy scenarios.

The goal of the study was to determine if the horizontal and unsigned vertical trajectory prediction accuracy of URET DU was influenced statistically by the ACT-250 time shifting techniques. Four runs were performed on the URET Delivery 3.1 Daily Use system in the WJHTC Traffic Flow Management Laboratory using a five hour Memphis ARTCC traffic scenario from May 26, 1999. The URET system was run in single center mode for this test, and the four runs included a control run where no time shifting was applied at all, a 20 and then a 40 percent time compression run, and finally a random time shifting run. The 20 percent time compression and random time shift runs were implemented to at most shift a flight by one hour earlier. The 40 percent time compression would at most shift a flight by two hours earlier.

One hundred flights were randomly selected from the five hour scenario and implemented into a statistical model. The model was developed to examine the influence of the time shifting, look ahead time, and the particular flight on the horizontal and vertical trajectory errors. As expected, look ahead time from zero to 20 minutes into the future and the difference between individual flights had a significant influence on trajectory accuracy. In all the statistical tests, the time shifting techniques did not statistically effect the unsigned vertical error. However, the time shifting for 40 percent time compression did have a statistically significant effect on the horizontal trajectory prediction error. The 40 percent time compression (that can at most move a flight two hours earlier in this experiment) did influence the horizontal error, but the magnitude of the effect was only about one nautical mile on average as compared to the control run. It is difficult to speculate on the cause of this influence. It is known that the wind and temperature forecasts used in the trajectory predictions are influential in the predictions, and time shifting a flight will cause incorrect weather data to be used in those predictions. Further study would need to be performed to determine if this weather deviation was the only cause for the influence.

The important result of this study is that time shifting of up to an hour in the form of 20 percent time compression and in randomly time shifting with a uniform distribution does not statistically effect trajectory accuracy. Although not a constraint due to the specification refresh process, this result can be used as a guideline in the later accuracy scenario generation process by ACT-250.

1 Introduction

1.1 Background

The Federal Aviation Administration (FAA) has contracted with the Lockheed Martin Corporation Air Traffic Management Division (LMATM) to develop and deploy a Conflict Probe Decision Support Tool. The deployment is limited to seven Enroute Air Traffic Control Centers to meet the FAA's Free Flight Phase 1 objective. The limited deployment of the Conflict Probe application is called the User Request Evaluation Tool Core Capability Limited Deployment (URET CCLD). The URET CCLD application is based on the MITRE developed URET Daily Use (URET DU) system installed in Indianapolis and Memphis Centers.

The FAA has tasked the Traffic Flow Management Branch, ACT-250, at the FAA W. J. Hughes Technical Center in Atlantic City to supply LMATM scenarios of realistic air traffic to perform acceptance testing of their system. In particular, these scenarios are to support the accuracy testing and will be used to verify the accuracy requirements of URET CCLD.

AOS-610, in conjunction with ACT-250 and MITRE, has collected air traffic data from the Indianapolis (ZID) and Memphis (ZME) Air Route Traffic Control Centers (ARTCCs). This data will be modified to produce the test scenarios. The data will be modified by shifting the start times of aircraft flights and possibly by cloning selected flights. These modifications are made to induce encounters between the aircraft in the test scenarios, while maintaining the actual routes and profiles the aircraft originally flew.

1.2 Purpose

This document describes a brief study performed by ACT-250 to determine if the trajectory prediction accuracy of the URET Delivery 3.1 DU system (i.e. URETD31_R3_P8) would be significantly degraded by the techniques planned for inducing encounters. These techniques, described later in Section 3, effectively shift each flight in time. A potential consequence of the shift in time is the trajectory modeling algorithms in URET or later in URET CCLD will make predictions based on weather forecast information no longer correlated to the original path of the aircraft. This is not a major concern in the Accuracy Testing of URET CCLD, since the specifications will be refreshed with metrics calculated by running URET DU with the identical scenario. However, the study will aid ACT-250 scenario developers in assigning their time shift parameters, so as to minimize the effect of time shifting on the trajectory prediction accuracy while still attaining the desired results for the Accuracy Testing (i.e. inducing the required number of encounters between aircraft-aircraft and aircraft-airspace).

1.3 Scope

The scope of this document is to describe a brief study on trajectory prediction accuracy degradation caused by time shifting flights in an effort to induce encounters for the URET CCLD Accuracy Testing. The study will test the hypothesis that time shifting using the techniques of time compression or random time shifting has no effect on the trajectory accuracy of URET DU.

1.4 Document Organization

The document first provides an overview of the study in Section 2. Next in Section 3, the document defines the time shifting techniques, which are the focus of the study. In Section 4, the trajectory prediction accuracy metrics used as the response variables of the study are described. The standard least square statistical model used in the study is then defined in Section 5. Finally in Sections 6 and 7, the results are presented and analysis conclusions are presented. In addition, Appendix A presents listings of the raw output tables produced by the statistical software package used for the analysis, namely SAS JMP [9].

2 Overall Description of the Experiment

The experiment consisted of extracting traffic data from Memphis ARTCC field recordings and generating four five hour traffic scenarios. Using this same source for traffic data, the four scenarios included:

1. a control scenario with no time shifting (for comparison purposes),
2. a time compressed scenario at 20 percent,
3. a time compressed scenario at 40 percent,
4. and a randomly time shifted scenario using a uniform distribution for up to an hour earlier.

The traffic scenarios were run through the URET DU (D3.1) in single center operation in the WJHTC Traffic Flow Management Laboratory. Next, the traffic scenarios and recorded trajectories were evaluated by ACT-250 using a suite of tools developed for and documented in the May 1999 report, *Trajectory Prediction Accuracy Report: URET/CTAS* [8]. The results were then statistically analyzed using Standard Least Square modeling [3] [9].

2.1 Statement of the Problem

As presented in Section 1, the FAA has tasked ACT-250 to produce traffic scenarios for the Accuracy Testing of URET CCLD. These traffic scenarios need to include a specified number of encounters between aircraft and aircraft and aircraft and airspace. To accomplish this, ACT-250 plans to employ two basic time shifting techniques that effectively move flights in one dimension, time. A potential consequence of time shifting techniques is the risk in degrading the trajectory prediction accuracy of the URET DU or URET CCLD system under measurement. Therefore, the focus of this study is to determine if the trajectory prediction accuracy does degrade under representative time shifting designs.

This study will test the hypothesis that time shifting aircraft in a recorded traffic scenario does not have a statistically significant effect on the mean horizontal and unsigned-vertical trajectory prediction accuracy of URET DU[1] from 0 to 20 minutes into the future. If time shifting is found to have a statistically significant effect on the mean horizontal or unsigned-vertical trajectory prediction accuracy of URET, the particular level (i.e. fixed conditions) of time shifting responsible for the effect will be determined. Finally, the magnitude of the statistically significant effect on trajectory accuracy will be ascertained.

2.2 Source Traffic Data & Scenarios

The traffic data used in this study was recorded on May 26, 1999 in the Memphis ARTCC UTC time 1100 to 1600 hours. The traffic data corresponds to the May 20, 1999 adaptation chart cycle. The five hour scenario duration was chosen, since ACT-250 plans to deliver scenarios in the same increment for the accuracy scenario task. The recorded weather files from May 26, 1999 were also used in the study but not time shifted in any way. URET DU was run in single center mode only for this experiment.

[1] The exact URET DU release run for this test is “URETD31_R3_P8”.

3 Discussion of the Independent Variables in the Experiment

The focus of this study is time shifting and whether it has a significant effect on trajectory accuracy; however, other factors must be considered as well, since they do have a significant effect on accuracy. The other factors or independent variables in this experiment include look ahead time and the effect caused by the differences between each sample flight, which pools all the other potential unknown factors.

3.1 Time Shifting

Time shifting is the process of adding a constant time value to all the Host Computer System (HCS) messages for a particular flight. The time value or shift in time is different for each flight but constant for each individual flight's messages. In other words, the aircraft's relative path and velocity does not change only the exact position relative to time along the path changes. Although a time shift can move a flight earlier in time (negative time change) or later in time (positive time change), only early shifts were exercised in this study. ACT-250 expects to employ two basic time shifting techniques in the scenario generation process, time compression and random time shifting. Note, the following Sections 3.1.1 and 3.1.2 do present more detail on these techniques sufficient for this study, however refer to reference [7] for a complete description.

3.1.1 Time Compression

Time compression is calculated by determining the time difference between a flight's first track position and the first track position of the earliest flight in the given traffic scenario and later multiplying a constant percentage value by this time difference. The result is the constant time value or shift in time to apply to all the particular flight's HCS messages. The entire scenario is multiplied by the same percentage, but each individual flight's actual time shift value will vary depending on its time difference with the earliest flight. If the percentage is less than 100 percent, all the tracks will effectively be time shifted closer in time. A result of this technique is a flight later in the scenario will be time shifted much more in magnitude than a flight earlier because of the larger time difference between the first flight's entry time. For a five hour scenario, the most a flight can be shifted in time if the time compression percentage is 20 percent is one hour earlier. Referring to Figure 1 as an example of a 20 percent compression, if the first flight entered the scenario at 1100 hours and the last flight entered at 1600 hours the time difference is five hours, resulting in a time shift value of one hour. Note, for this example this last flight would only have one track position in the scenario.

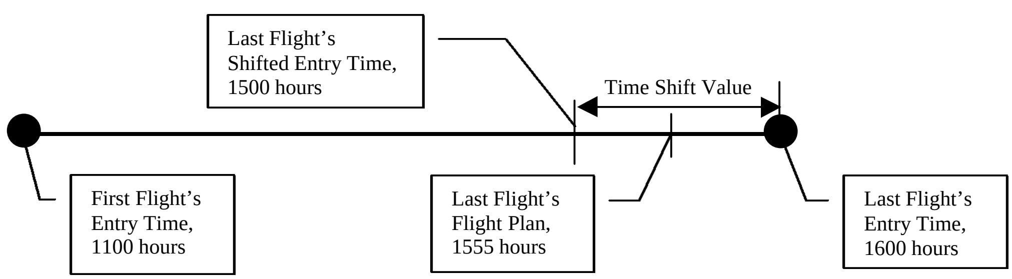


Figure 1: Time Compression Example

For this study with a five hour scenario, two time compression percentages were used. One at 20 percent compression which will cause at most a one hour time shift earlier, and the other at a 40 percent compression which will at most cause a two hour time shift earlier.

3.1.2 Randomly Time Shifting

Randomly time shifting means applying a pseudo random number generator to determine a value to time shift an individual flight's HCS messages. By using a random variate, a distribution can be mapped to the random number generator. For example, if a Normally distributed random number is required, the mean and variance of the Normal Distribution is chosen for all flights of the scenario. As a result, the generated Normally Distributed time shift value will be applied to each flight's HCS messages. Like the time compression percentage was chosen in time compression, the distribution and parameters of that distribution can be set for desired effects. Unlike time compression, randomly time shifting can allow some flights to be time shifted earlier and others to be time shifted later all in one scenario. One design constraint chosen using this technique is to truncate the distribution at the earliest flight's entry time to prevent a flight from being shifted before the original scenario started. Therefore, no flight will enter the scenario earlier than the originally earliest flight.

For this study, a one sided uniform distribution was chosen from –3600 to 0 seconds. In other words, for each flight a pseudo random number generator is utilized to generate a number between –3600 to 0 seconds. This effectively shifts all flights 0 to 3600 seconds earlier.

3.1.3 The Control Scenario

The Control Scenario is not time shifted at all, but acts as the basis for comparison in the study. All flights in the Control Scenario enter as they actually did on May 26, 1999.

3.2 Look Ahead Time

The look ahead time is defined by ACT-250 as the difference in the time point at which the accuracy metric is computed for a sampled trajectory/track position and a base time. The base time represents the first calculation of the metric taken among a sequence. Look ahead time is defined in more detail and proven to cause a statistically significant effect on trajectory accuracy in the May 1999 report, *Trajectory Prediction Accuracy Report: URET/CTAS* [8]. Therefore, the Look Ahead Time Factor is included in this study simply as a fixed restriction on the experiment and to determine if there exists any interaction with the Time Shifting Factor.

For this experiment, the look ahead time will be used at 0, 300, 600, 900, and 1200 seconds (i.e. 0 to 20 minutes).

3.3 Flight

The individual flight is the last factor considered in this study. It was specifically utilized in the experiment to pool all the unknown factors that potentially effect trajectory prediction accuracy. Like replications of a day or sequence in a lot experiment, the flight is a restriction on the randomization of the experiment. For example, flight type, equipage, aircraft type, airline, etc. are all factors which potentially effect the trajectory prediction accuracy, but by including the flight as a specific factor their effects are effectively blocked in the experiment.

For this study, 100 flights are randomly chosen out of the five hour traffic scenario. The same 100 flight's trajectory prediction data is extracted for each run and used for the later statistical analysis.

4 Discussion of the Dependent Variables in the Experiment

Trajectory prediction accuracy is a measure of the performance of URET's trajectory modeling algorithms, which form the basis for all the other predictions made by the decision support tool. The details of the specific sampling methods applied to measure trajectory prediction accuracy are documented in the May 1999 report, see reference [8].

For this study, the response or dependent variables of the experiment are the flight's mean horizontal and unsigned vertical error.

4.1 Mean Horizontal Error

The mean flight error in the horizontal plane is estimated by calculating the average horizontal error in nautical miles for all the sample points at a particular look ahead time. The horizontal error measurement is the distance between the actual track position and time coincident sampled trajectory predicted position.

4.2 Mean Unsigned Vertical Error

The mean flight error in the vertical plane is estimated by calculating the average vertical error in feet for all the sample points of a particular look ahead time. The vertical error measurement is the distance between the actual track position reported altitude and time coincident sampled trajectory predicted altitude.

5 Design of Statistical Model to Test Hypothesis

The designed experiment is a two factor experiment in a randomized block design [3]. In other words, the two factors of the experiment being Time Shift and Look Ahead Time are blocked by the Flight Factor. Therefore, the randomized block model is:

$$Y_{ijkm} = m + F_k + t_{ij} + e_{m(ijk)} \qquad \textbf{Equation 1}$$

The Y_{ijkm} term represents each observation in the experiment, where the "i" refers to the ith level of the Time Shift Factor, the "j" refers to the jth level of the Look Ahead Time Factor, the "k" refers to the kth level of the Flight Factor, and the "m" refers to the mth observation within each treatment and block. The m term represents the common effect for the whole experiment. The $e_{m(ijk)}$ represents the error term and is considered normally and independently distributed (NID) random effect whose mean value is zero and variance is the same for all treatments or levels. The F_k in the model represents the Flight or Block Factor at the kth level. The t_{ij} in the model represent the treatments. In this study, the treatments are formed from a two factor factorial experiment, with:

$$t_{ij} = T_i + L_j + TL_{ij} \qquad \textbf{Equation 2}$$

The T_i represents the Time Shift Factor at the ith level and the L_j represents the Look Ahead Time Factor at the jth level. The interaction between the Time Shift and Look Ahead Time Factors is represented by TL_{ij}. The interaction is the influence on the response variable by the combination of both Time Shift and Look Ahead Time Factors, simultaneously. The model's factors and the degrees of freedom are listed in Table 1.

Table 1: Model Breakdown

Source	Degrees of Freedom	
Blocks (Flights) F_k	99	
Treatments t_{ij}	19	
Time Shift T_i		3
Look Ahead Time L_j		4
Interaction TL_{ij}		12
Error e_{ijk}	1881	
Total	1999	

6 Results of Statistical Test on Experiment

Using the SAS JMP software package, the four runs with the five look ahead times were implemented into a factorial experiment as described in Section 5 [9]. The results are listed in Table 2 for the horizontal error response variable and Table 3 for the unsigned vertical error response variable.

Table 2: Full Experiment Model Results for Horizontal Error[2]

Source	Degree of Freedom	Sum of Squares	F Ratio	Prob>F
Time Shift	3	165.491	5.5712	0.0008
Look Ahead Time (LH)	4	6842.926	172.773	<.0001
Flight	99	16768.26	17.1059	<.0001
Time Shift * LH	12	16.292	0.1371	0.9998
Rsquare Value	0.63			

Table 3: Full Experiment Model Results for Vertical Error[3]

Source	Degree of Freedom	Sum of Squares	F Ratio	Prob>F
Time Shift	3	1638893	1.3978	0.2418
Look Ahead Time (LH)	4	173827147	111.1920	<.0001
Flight	99	867360246	22.4171	<.0001
Time Shift * LH	12	578703	0.1234	0.9999
Rsquare Value	0.64			

From the Rsquare Value reported in Table 2, 63 percent of the variation is explained by the model for horizontal prediction error, and in Table 3, 64 percent of the variation is explained by the model for vertical prediction error. In both experiments, the interaction between the Time Shift Factor and Look Ahead Time is insignificant, and Look Ahead Time and Flight are very significant effects on the model. However, for vertical error Time Shift is statistically insignificant, while in the horizontal error experiment Time Shift is statistically significant with Type I or Alpha of 0.10 or even 0.01.

Since the Time Shift Factor is significant for the horizontal error, the test has rejected the hypothesis that time shifting does not statistically effect the horizontal trajectory prediction accuracy. The next question to be answered is what level or levels of this factor is responsible for the statistical effect. For the Time Shift Factor, four levels were tested: the control, time compression by 20 percent, time compression by 40 percent, and random time shifting forward by 1 hour. To determine the level or levels responsible for the statistical effect, further analysis was performed to compare all pairwise combinations of the Time Shift levels. In Appendix A.2, a diagram of each Time Shift level's quantiles is presented as well as the quantile listings. Figure 2 illustrates the sample mean for each Time Shift level connected by a line, and above and below the sample mean are horizontal bars representing one standard error (i.e. one standard deviation divided by the square root of the sample size). Table 4 lists the actual sample means, sample standard deviation, and standard errors for each Time Shift level. Referring to both Figure 2 and Table 4, the Time

[2] The source of this data is the SAS JMP software Standard Least Squares "Fit a Model" function [9]. Refer to Appendix A.1 for a complete listing of the SAS JMP output tables.
[3] Same as footnote for Table 2.

Shift level of 40 percent time compression was roughly one nautical mile higher on average than the control and almost that compared to the other Time Shift levels.

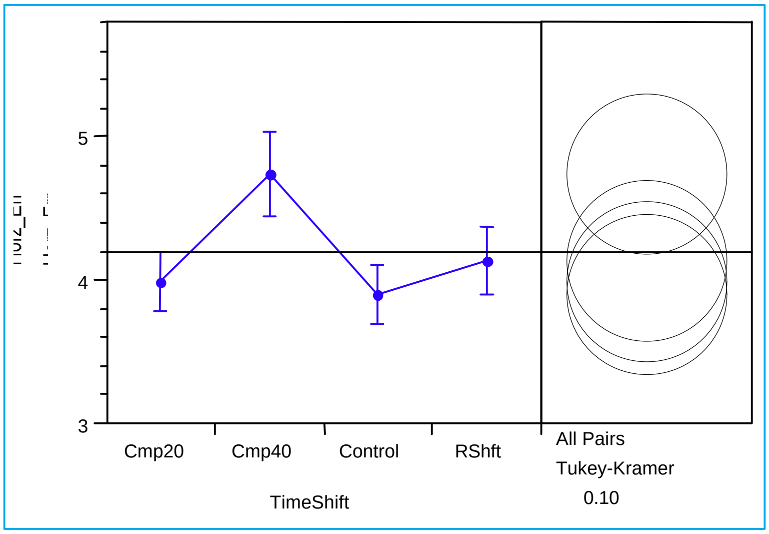


Figure 2: Horizontal Error by Time Shift Level

Table 4: Time Shift Level Mean and Standard Deviations

Time Shift Level	Number	Mean (nm)	Std Dev (nm)	Std Err Mean (nm)
Cmp20	404	4.19583	4.43101	0.22045
Cmp40	404	4.95804	6.11588	0.30428
Control	399	4.10348	4.34461	0.21750
RShft	401	4.33753	4.80108	0.23975

The Tukey-Kramer Statistical Test was then employed to determine which of the levels were different statistically [8] [9][4]. In Table 5, the difference in sample mean between each pairwise combination is calculated. The values are then used in the Tukey-Kramer Test and using an Type I or Alpha error of 0.10 determines which pairwise combination difference is statistically significant.

Table 5: Time Shift Level Mean Comparisons

Dif=Mean[i]-Mean[j]	Cmp40 (nm)	RShft (nm)	Cmp20 (nm)	Control (nm)
Cmp40	0.000000	0.620518	0.762216	0.854563
RShft	-0.62052	0.000000	0.141699	0.234045
Cmp20	-0.76222	-0.1417	0.000000	0.092347
Control	-0.85456	-0.23405	-0.09235	0.000000

[4] See reference [8] Appendix A.0.4 for a more complete description of this statistical test.

Table 6: Comparisons for all pairs using Tukey-Kramer HSD[5]

	q* = 2.29320		Alpha= 0.10	
Abs(Dif)-LSD	Cmp40 (nm)	RShft (nm)	Cmp20 (nm)	Control (nm)
Cmp40	-0.8029	-0.18389	-0.04069	0.049148
RShft	-0.18389	-0.8059	-0.66271	-0.57287
Cmp20	-0.04069	-0.66271	-0.8029	-0.71307
Control	0.049148	-0.57287	-0.71307	-0.80792

Table 6 lists the results of the Tukey-Kramer Test as performed by the JMP software package. Any positive comparison test value in Table 6 represents a statistically significant difference. Graphically in Figure 2, the circles that overlap considerably are not significantly different and ones that do not are significant. The only positive value in Table 6 and circles that do not overlap considerably in Figure 2 is the difference between the control and the 40 percent comparison. Therefore, the Tukey-Kramer Test confirms the earlier indications where 40 percent compression had a relatively larger sample mean compared to the other levels. Also, Table 6 confirms that the other Time Shift Levels are not statistically different with 90 percent confidence (Alpha error of 0.10).

The comparison of the Time Shift Factor levels suggest that the effect on horizontal error is due only to the 40 percent time compression and not significantly from the other levels. Therefore, the original model was rerun through the SAS JMP software tool without the 40 percent compression data. Referring to Table 7, the results did confirm the previous findings. The Time Shift levels of 20 percent time compression, random time shifting, and the control run without any time shifting did not significantly effect the horizontal prediction error. For the complete JMP table listings including the vertical error experiment which had similar results, refer to Appendix A.3.

Table 7: Partial Experiment Model Results for Horizontal Error

Source	Degree of Freedom	Sum of Squares	F Ratio	Prob>F
Time Shift	2	9.948	0.7858	0.4560
Look Ahead Time (LH)	4	5176.796	204.4552	<.0001
Flight	99	11559.940	18.4466	<.0001
Time Shift * LH	8	15.110	0.2984	0.9666
Rsquare Value	0.72			

[5] Positive values show pairs of means that are significantly different. See Reference [8] for description of Tukey-Kramer technique.

7 Conclusions

The overall goal was to determine if the horizontal and unsigned vertical trajectory prediction accuracy of URET DU was influenced statistically by the ACT-250 time shifting techniques. In summary, four runs were performed on the URET D3.1 Daily Use system in the WJHTC Traffic Flow Management Laboratory. The traffic data used for the runs was the same five hour traffic scenario from May 26, 1999. The data was collected in the Memphis ARTCC and the URET system was run in single center mode for this test.

The four runs included a control run where no time shifting was applied at all, a 20 and then a 40 percent time compression run, and finally a random time shifting run. The 20 percent time compression and random time shift runs were implemented to at most shift a flight earlier by one hour. The 40 percent time compression would at most shift a flight earlier by two hours.

One hundred flights were randomly selected from the five hour scenario and implemented into a statistical model. The model was developed to examine the influence of the time shifting, look ahead time, and the particular flight on the horizontal and vertical trajectory errors. Look ahead time from zero to 20 minutes into the future and the difference of individual flights had a significant influence on trajectory accuracy, as expected. In all statistical tests, the time shifting techniques did not statistically effect the unsigned vertical error. However, the time shifting for 40 percent time compression did have a statistically significant effect on the horizontal trajectory prediction error. The 40 percent time compression (that can at most move a flight two hours earlier in this experiment) did influence the horizontal error, but the magnitude of the effect was only about one nautical mile on average as compared to the control run. It is difficult to speculate on the cause of this influence. It is known that the wind and temperature forecasts used in the trajectory predictions are influential in the predictions, and time shifting a flight will cause incorrect weather data to be used in those predictions. Further study would need to be performed to determine if this weather deviation was the only cause for the influence.

The important result of this study is that time shifting of up to an hour in the form of 20 percent time compression and in randomly time shifting with a uniform distribution does not statistically effect trajectory accuracy. Although not a constraint due to the specification refresh process, this can be used as a guideline in the later accuracy scenario generation process by ACT-250.

Acronyms

ACT	-	FAA Designator for the William J. Hughes Technical Center
AOS	-	FAA Designator for Operational Support
ARTCC	-	Air Route Traffic Control Center
DST	-	Decision Support Tool
FAA	-	Federal Aviation Administration
HCS	-	Host Computer System
IFR	-	Instrument Flight Rules
LH	-	Look Ahead Time
LM	-	Lockheed Martin
LMATM	-	Lockheed Martin Air Traffic Management
MITRE CAASD	-	MITRE Center for Advanced Aviation System Development
NID	-	Normally and Independently Distributed random variable
nm	-	nautical mile(s)
NWS	-	National Weather Service
SAS JMP	-	SAS Jump (i.e. statistical software package made by SAS)
SAS	-	Statistical Analysis System, Inc.
SSD	-	System Specification Document (written by FAA)
SSS	-	System Segment Specification (written by LM)
URET CCLD	-	User Request Evaluation Tool Core Capability Limited Deployment
URET DU	-	User Request Evaluation Tool Daily Use
URET	-	User Request Evaluation Tool
UTC	-	Universal Time Coordinated
WJHTC	-	William J. Hughes Technical Center
ZID	-	Indianapolis ARTCC
ZME	-	Memphis ARTCC

References

1. Devore, J., *Probability and Statistics for Engineering and the Sciences*, *Second Edition*, Brooks/Cole Publishing Company, 1987.

2. Federal Aviation Administration (October 1998), *User Request Evaluation Tool Core Capability Limited Deployment System Specification Document*, FAA-ER-2929.

3. Hicks, C., *Fundamental Concepts in the Design of Experiments, Fourth Edition*, Saunders College Publishing, 1993.

4. Kelton, D., Law, A., *Simulation Modeling And Analysis*, *Second Edition*, McGraw-Hill, Incorporated, New York, 1991.

5. Lockheed Martin Air Traffic Management (August 1998), *User Request Evaluation Tool (URET) Core Capability Limited Deployment (CCLD) System/Segment Specification (SSS) Volume 1, Part2: Conflict Probe (CP)*, FAA-AP-1998-1089, CDRL IA093, Rockville, Maryland.

6. Montgomery, Douglas, C., *Introduction to Statistical Quality Control*, *Second Edition*, John Wiley and Sons, Inc., 1991.

7. Paglione, M., Ryan, Dr. H., Summerill, J. S., Oaks, R. (Draft, August 1999), *Description of the Methodology for the Generation of Accuracy Scenarios for Acceptance Testing of the User Request Evaluation Tool / Core Capability Limited Deployment*, FAA William J. Hughes Technical Center/ACT-250, Atlantic City, New Jersey.

8. Paglione, M., Ryan, Dr. H., Summerill, J. S., Oaks, R., Cale, M. (May 1999), *Trajectory Prediction Accuracy Report: URET/CTAS*, DOT/FAA/CT-TN99/10, FAA William J. Hughes Technical Center/ACT-250, Atlantic City, New Jersey.

9. SAS Institute, *JMP Statistics and Graphics Guide, Version 3, JMP Software Package*, 1995.

Appendix A: JMP Output Tables

The following sub-sections are simply a listing of the SAS JMP software output for the experiment defined in this study [9]. Section A.1 lists the output for the full experiment with all four time shift levels. Section A.2 lists the output for the partial experiment absent the 40 percent time compression level. For detailed explanations of the meaning of these tables, see reference [9] and reference [8] Appendix A.0.

A.1. Full Experiment

Response: Horz_Err

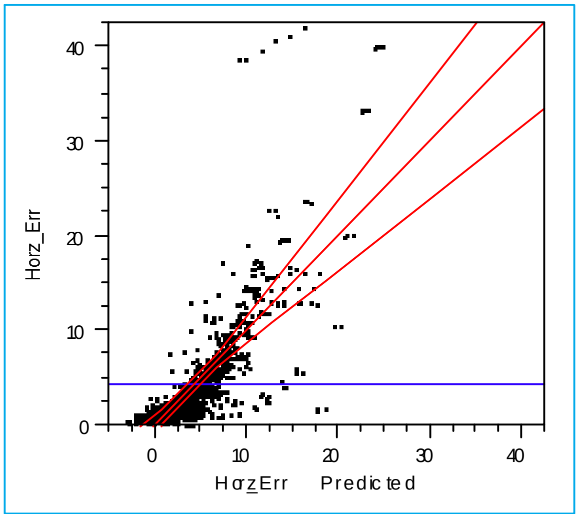
Summary of Fit

RSquare	0.630471
RSquare Adj	0.601187
Root Mean Square Error	3.146686
Mean of Response	4.399752
Observations (or Sum Wgts)	1608

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
TimeShift	3	3	165.491	5.5712	0.0008
LH	4	4	6842.926	172.7726	<.0001
Flight	99	99	16768.261	17.1059	<.0001
TimeShift*LH	12	12	16.292	0.1371	0.9998

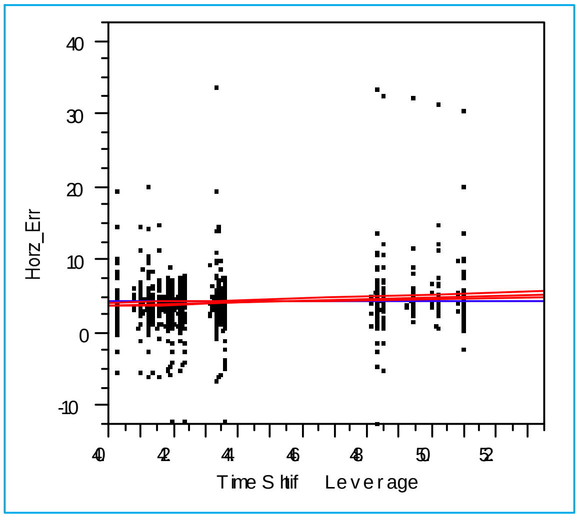
Whole-Model Test



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	118	25154.664	213.175	21.5293
Error	1489	14743.535	9.902	Prob>F
C Total	1607	39898.198		<.0001

TimeShift



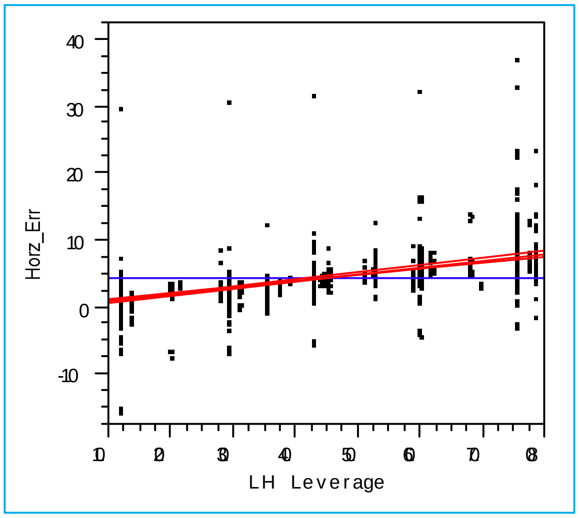
Effect Test

Sum of Squares	F Ratio	DF	Prob>F
165.49112	5.5712	3	0.0008

Least Squares Means

Level	Least Sq Mean	Std Error	Mean
Cmp20	4.557415381	0.1657229258	4.19583
Cmp40	5.323423969	0.1657229258	4.95804
Control	4.501539085	0.1675539340	4.10348
RShft	4.719918644	0.1666092892	4.33753

LH



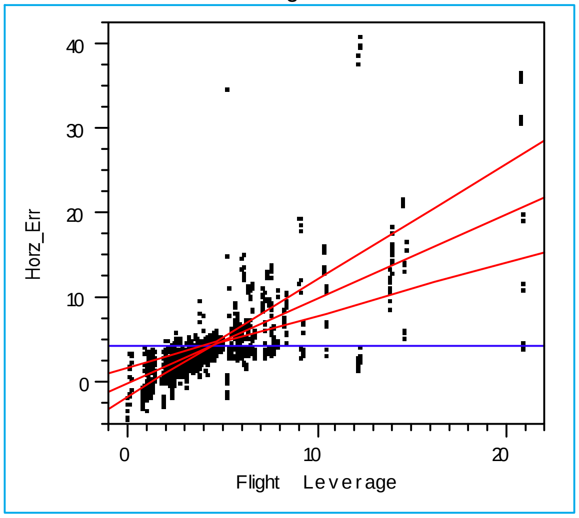
Effect Test

Sum of Squares	F Ratio	DF	Prob>F
6842.9264	172.7726	4	<.0001

Least Squares Means

Level	Least Sq Mean	Std Error	Mean
0	1.555953711	0.1575659261	1.56036
300	3.301028813	0.1656492625	3.32990
600	4.652613837	0.1879297308	4.62750
900	6.368555066	0.2037479001	6.48272
1200	7.999719922	0.2195814834	8.13869

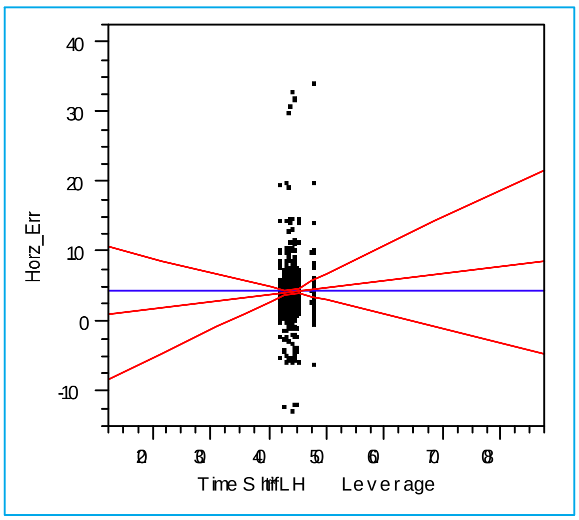
Flight



Effect Test

Sum of Squares	F Ratio	DF	Prob>F
16768.261	17.1059	99	<.0001

TimeShift*LH



Effect Test

Sum of Squares	F Ratio	DF	Prob>F
16.291758	0.1371	12	0.9998

Response: Vert_Err

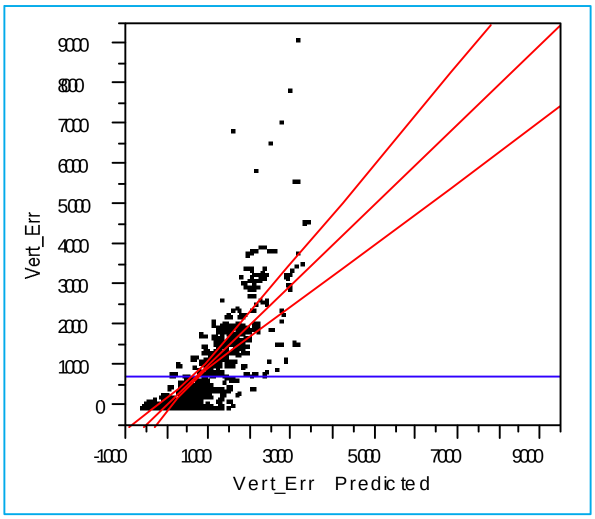
Summary of Fit

RSquare	0.644568
RSquare Adj	0.616401
Root Mean Square Error	625.1611
Mean of Response	712.8652
Observations (or Sum Wgts)	1608

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
TimeShift	3	3	1638893	1.3978	0.2418
LH	4	4	173827147	111.1920	<.0001
Flight	99	99	867360246	22.4171	<.0001
TimeShift*LH	12	12	578703	0.1234	0.9999

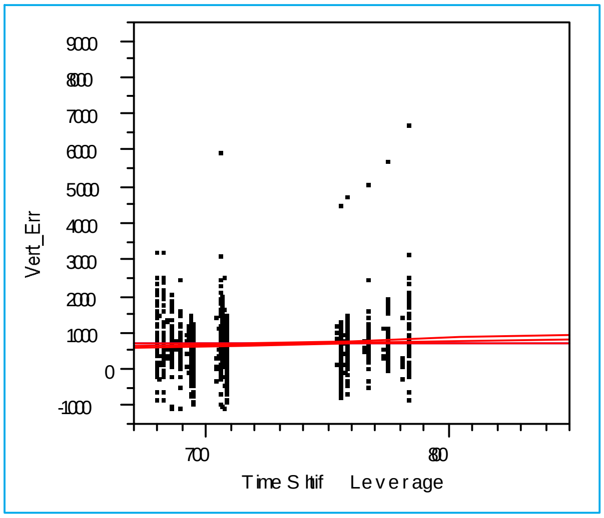
Whole-Model Test



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	118	1055336458	8943529	22.8836
Error	1489	581940604	390826	Prob>F
C Total	1607	1637277062		<.0001

TimeShift



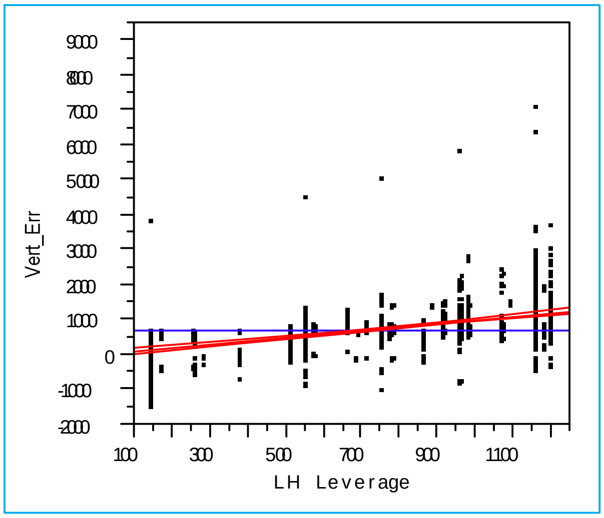
Effect Test

Sum of Squares	F Ratio	DF	Prob>F
1638893.4	1.3978	3	0.2418

Least Squares Means

Level	Least Sq Mean	Std Error	Mean
Cmp20	762.7121138	32.92464619	692.212
Cmp40	841.4135050	32.92464619	765.499
Control	761.9836006	33.28841780	689.116
RShft	780.7780344	33.10074253	704.277

LH



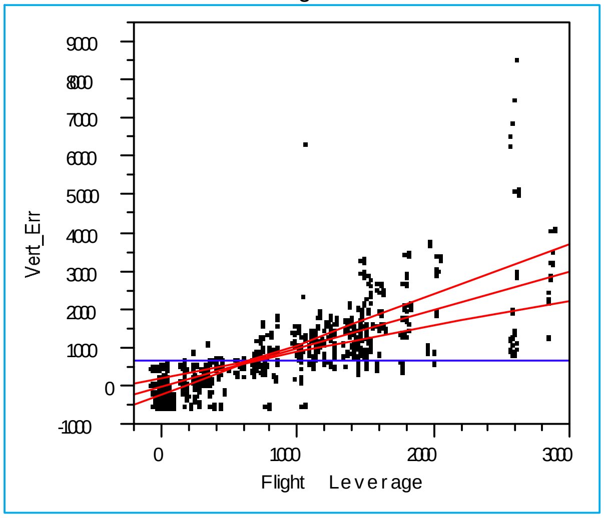
Effect Test

Sum of Squares	F Ratio	DF	Prob>F
173827147	111.1920	4	<.0001

Least Squares Means

Level	Least Sq Mean	Std Error	Mean
0	217.907390	31.30407180	219.02
300	621.433922	32.91001128	622.98
600	822.095712	37.33653545	812.88
900	1030.616281	40.47917624	1008.65
1200	1241.555762	43.62487939	1207.27

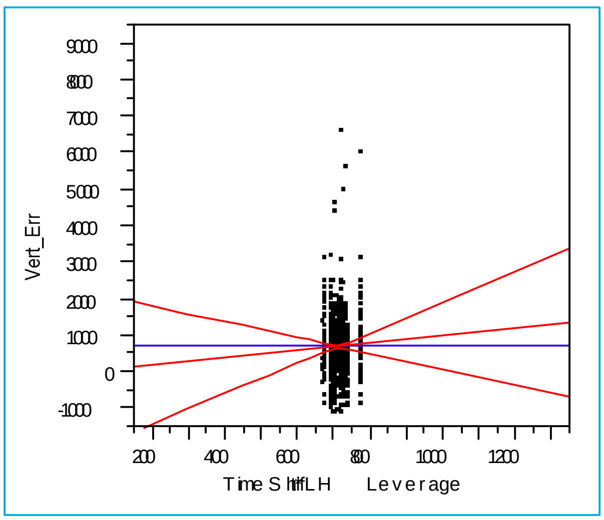
Flight



Effect Test

Sum of Squares	F Ratio	DF	Prob>F
867360246	22.4171	99	<.0001

TimeShift*LH

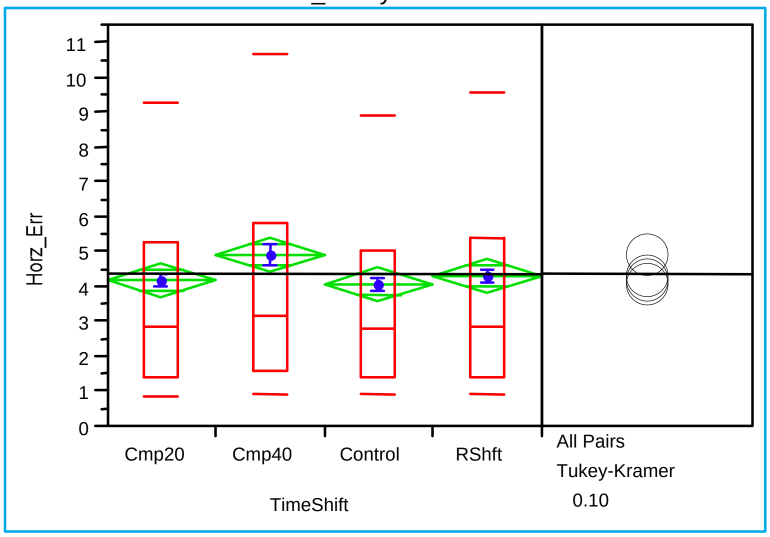


Effect Test

Sum of Squares	F Ratio	DF	Prob>F
578702.83	0.1234	12	0.9999

A.2. Analysis of Time Shift Levels on Horizontal Error

Horz_Err By TimeShift[6]



Quantiles

Level	minimum	10.0%	25.0%	median	75.0%	90.0%	maximum
Cmp20	0.1937	0.90752	1.430251	2.887073	5.28823	9.30445	40.2319
Cmp40	0.1376	0.947981	1.607892	3.171706	5.848254	10.71099	42.07961
Control	0.377982	0.9213	1.46	2.82195	5.083625	8.903306	39.8625
RShft	0.1806	0.926221	1.463009	2.874721	5.444959	9.570898	40.2191

Means and Std Deviations

Level	Number	Mean	Std Dev	Std Err Mean
Cmp20	404	4.19583	4.43101	0.22045
Cmp40	404	4.95804	6.11588	0.30428
Control	399	4.10348	4.34461	0.21750
RShft	401	4.33753	4.80108	0.23975

Means Comparisons

Dif=Mean[i]-Mean[j]	Cmp40	RShft	Cmp20	Control
Cmp40	0.000000	0.620518	0.762216	0.854563
RShft	-0.62052	0.000000	0.141699	0.234045
Cmp20	-0.76222	-0.1417	0.000000	0.092347
Control	-0.85456	-0.23405	-0.09235	0.000000

Alpha= 0.10

Comparisons for all pairs using Tukey-Kramer HSD

q*2.29320

Abs(Dif)-LSD	Cmp40	RShft	Cmp20	Control
Cmp40	-0.8029	-0.18389	-0.04069	0.049148
RShft	-0.18389	-0.8059	-0.66271	-0.57287
Cmp20	-0.04069	-0.66271	-0.8029	-0.71307
Control	0.049148	-0.57287	-0.71307	-0.80792

Positive values show pairs of means that are significantly different.

[6] See Appendix A.0 in reference [8] for explanation of this table.

A.3. Partial Experiment (absent 40 percent time compression)

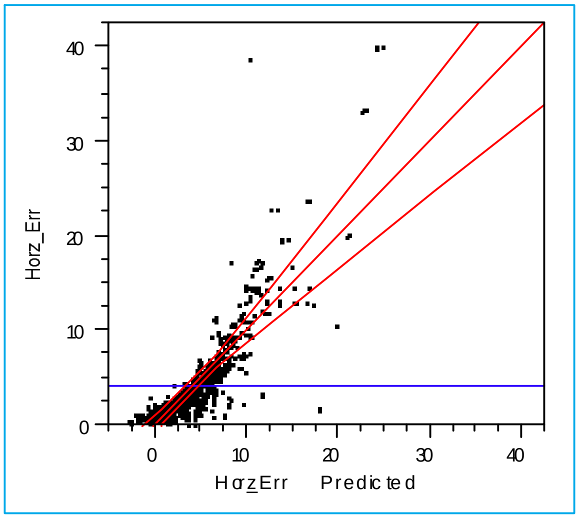
Response: Horz_Err
Summary of Fit

RSquare	0.720164
RSquare Adj	0.691154
Root Mean Square Error	2.515947
Mean of Response	4.212418
Observations (or Sum Wgts)	1204

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
TimeShift	2	2	9.948	0.7858	0.4560
LH	4	4	5176.796	204.4552	<.0001
Flight	99	99	11559.940	18.4466	<.0001
TimeShift*LH	8	8	15.110	0.2984	0.9666

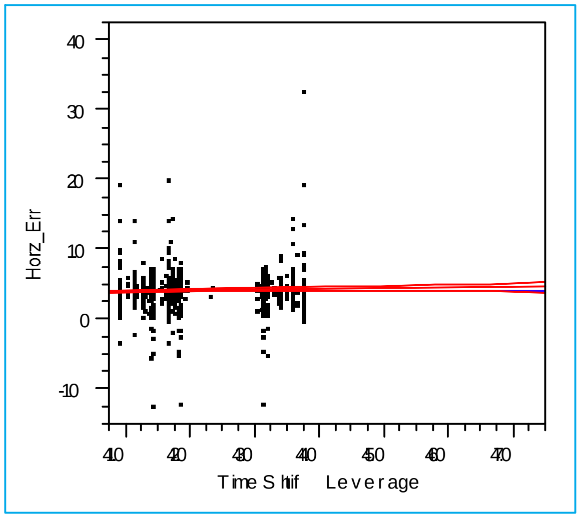
Whole-Model Test



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	113	17756.527	157.137	24.8243
Error	1090	6899.687	6.330	Prob>F
C Total	1203	24656.214		<.0001

TimeShift



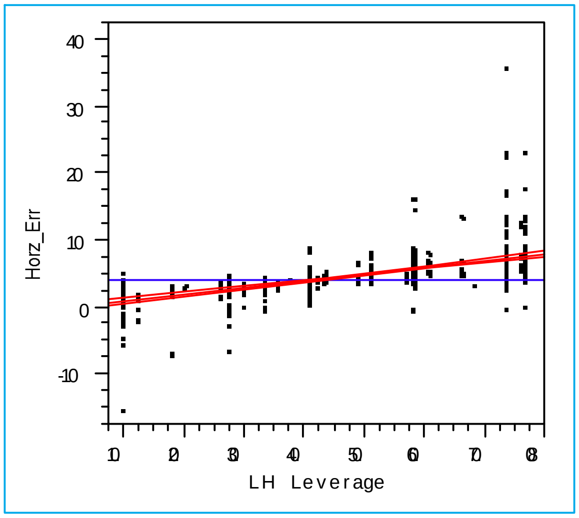
Effect Test

Sum of Squares	F Ratio	DF	Prob>F
9.9476413	0.7858	2	0.4560

Least Squares Means

Level	Least Sq Mean	Std Error	Mean
Cmp20	4.564927035	0.1341963351	4.19583
Control	4.511382478	0.1356677433	4.10348
RShft	4.729449299	0.1350396063	4.33753

LH



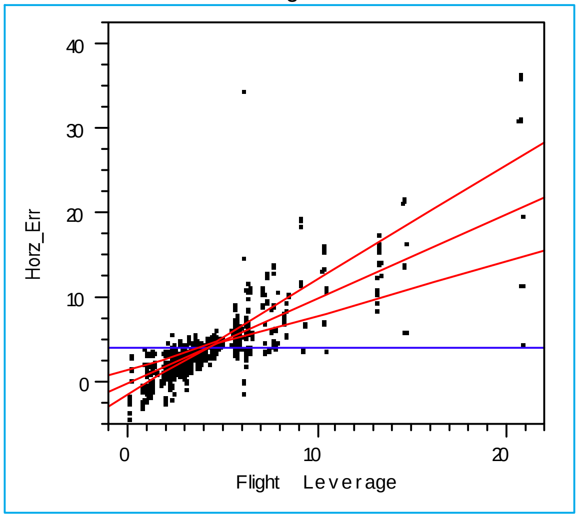
Effect Test

Sum of Squares	F Ratio	DF	Prob>F
5176.7961	204.4552	4	<.0001

Least Squares Means

Level	Least Sq Mean	Std Error	Mean
0	1.368877781	0.1455636386	1.37315
300	3.119985177	0.1530285456	3.14031
600	4.463157530	0.1735566025	4.42706
900	6.199929244	0.1882725276	6.31742
1200	7.857648287	0.2034927420	7.97038

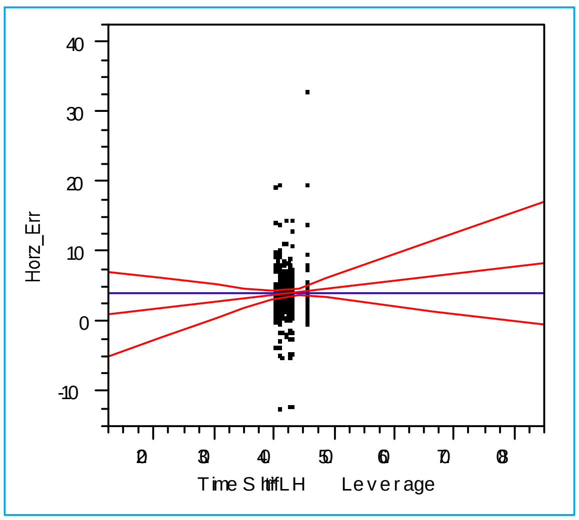
Flight



Effect Test

Sum of Squares	F Ratio	DF	Prob>F
11559.940	18.4466	99	<.0001

TimeShift*LH



Effect Test

Sum of Squares	F Ratio	DF	Prob>F
15.109558	0.2984	8	0.9666

Response: Vert_Err

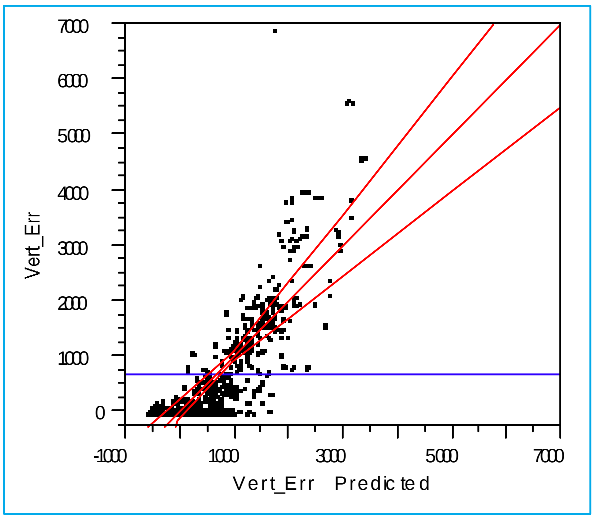
Summary of Fit

RSquare	0.689045
RSquare Adj	0.656808
Root Mean Square Error	551.7318
Mean of Response	695.2041
Observations (or Sum Wgts)	1204

Effect Test

Source	Nparm	DF	Sum of Squares	F Ratio	Prob>F
TimeShift	2	2	86184	0.1416	0.8680
LH	4	4	130021763	106.7825	<.0001
Flight	99	99	598036445	19.8443	<.0001
TimeShift*LH	8	8	486399	0.1997	0.9909

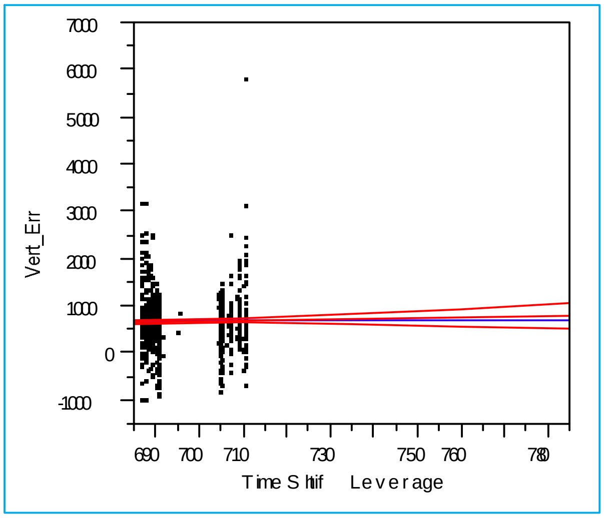
Whole-Model Test



Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	113	735245298	6506596	21.3746
Error	1090	331804704	304408	Prob>F
C Total	1203	1067050003		<.0001

TimeShift



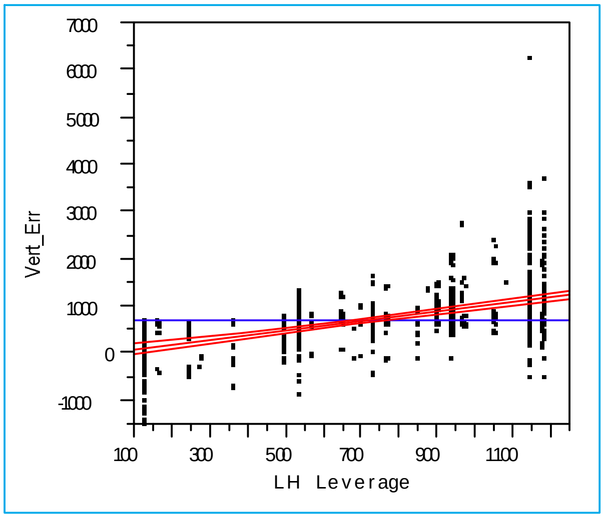
Effect Test

Sum of Squares	F Ratio	DF	Prob>F
86183.914	0.1416	2	0.8680

Least Squares Means

Level	Least Sq Mean	Std Error	Mean
Cmp20	766.2638196	29.42843913	692.212
Control	766.0898501	29.75110999	689.116
RShft	784.4679738	29.61336338	704.277

LH



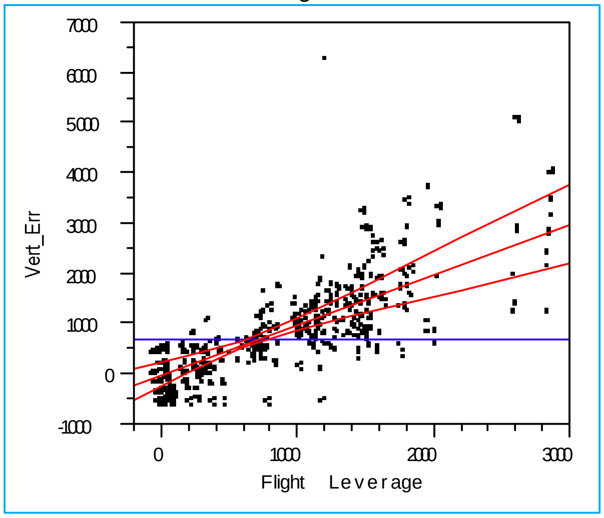
Effect Test

Sum of Squares	F Ratio	DF	Prob>F
130021763	106.7825	4	<.0001

Least Squares Means

Level	Least Sq Mean	Std Error	Mean
0	203.949076	31.92121956	205.33
300	608.532903	33.55822823	610.43
600	804.997930	38.05990610	792.33
900	1012.629365	41.28701887	983.95
1200	1231.260133	44.62471919	1189.85

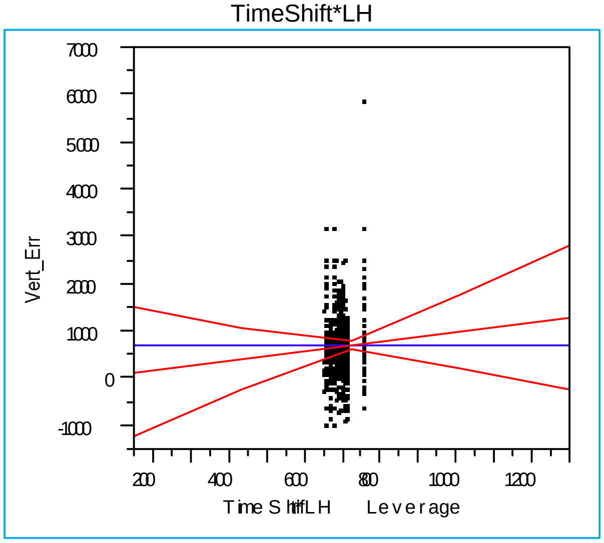
Flight



Effect Test

Sum of Squares	F Ratio	DF	Prob>F
598036445	19.8443	99	<.0001

TimeShift*LH



Effect Test

Sum of Squares	F Ratio	DF	Prob>F
486399.04	0.1997	8	0.9909